What are the common knowledge & competencies for Education for Sustainable Development and for Engineering Education for Sustainable Development?

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What are the common knowledge & competencies for Education for Sustainable Development and for Engineering Education for Sustainable Development?

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INTRODUCTION

Higher education is seen as a place for professional education and development. Some see academia main activities as fundamental to address the contemporary society challenges, like how to build a more sustainable future. Sustainable development is part of global and local agendas, both political and educational [1][2]. This paper aims to present a qualification framework based on the analysis of education for sustainable development (ESD) theories and engineering education for sustainable development (EESD) and bring together common understanding of the concepts and principles used in their discourses.

1 EDUCATION FOR SUSTAINABLE DEVELOPMENT & ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

Broadly, education can contribute for the goal of sustainable development by creating learning environments where students: **i)** actively develop positive attitudes and patterns of behaviour aligned that reflect the requirements of sustainable development; and/ or **ii)** explore and engage with sustainable issues through their own critical ability and interpretation. However these assumptions and frames raise problematic issues like the different interpretations of "sustainable development" in the educational context [3]. To some extent, the interpretation of education for sustainable development (ESD) depends on the context and it is set out from real practical problems. It is also claimed that its principles should not only be integrated in the curriculum but be also part of the vision of the educational system. The integration of sustainable development principles implies challenging changes at all institutional levels [2][4][5][5].
Core theories define and characterize ESD as: (i) rooted in postmodernism; (ii) social, constructivist and transformative; (iii) contextual, experimental and collaborative; (iv) process oriented and empowering; (v) problem solving, critical thinking and creative; etc. The characteristics and definition of ESD move from an epistemological perspective to a curriculum construction perspective [1][4][5][7][8].
Sterling [9][7] pointed twelve primary requirements that characterize education for sustainability. These requirements detailed some elements for defining competencies such as

lifelong learning, ethics, critical, system thinking, etc., and learning approach as contextual, participative, interdisciplinary, process oriented, etc. (*Table 1*).

Table 1. Characteristics of Education for Sustainability [9]

Characteristics of ESD	**Description**
1. Contextual	*Fully awake to and engaged in addressing the crises of modernity. Logically, education that reproduces modernism uncritically cannot effectively be engaged in resolving the crises modernism has created. Where, possible, EFS* (or ESD) *should be applied and grounded in the local economic, social and ecological context and community, followed by regional, national international and global contexts.*
2. Innovative and constructive	*Drawing inspiration from "new paradigm" postmodern thinking in a range of fields (including science, ethics, politics, economics, design and psychology) offering insights and ways forward that promise a safe, humane and environmentally sustainable rather than threatened and chaotic future.*
3. Focused and infusive	*Primarily grounded in, but not limited to, social development and human ecology, equity and futures, at the centre of a holistic approach which touches all other areas*
4. Holistic and human scale	*Recognizing that all educational dimensions, such as curriculum, pedagogy, structures, organization and ethos are mutually affecting and need to be seen as a consistent whole; and that this works best at a scale that relates to the needs of learners and educators. It is also holistic in the sense of being both learner-centred (development of the whole person) and socially oriented (reconstructionist).*
5. Integrative	*Greater emphasis on interdisciplinary and transdisciplinary enquiry, reflecting that no subjects, factors or issues exist in isolation. Transdisciplinary means breaking free of disciplinary perceptions and traditions to create new meanings, understandings, and way of working. Simply putting disciplines together, by contrast, is often no more than the sum of the parts*
6. Process oriented and empowering	*rather than product oriented – revisioning and revaluing education and learning as intrinsic to life. Education for sustainability is therefore engaged and participative rather than passive; the emphasis is on learning rather than teaching. In particular, action research with its emphasis on critical reflection, experimental learning cycles and democratic ownership of change is inherent if EFS* (or ESD).
7. Critical	*Ideologically aware and socially critical. Recognizing that no educational values are politically neutral, EFS* (or ESD) *should draw on the body of critical theory associated with deep green and red-green orientations as these constitute the prime challenge to the modernism hegemony. At the same time, it must continuously appraise this theory and its own rationale critically.*
8. Balancing	*Seeking to rebalance correlated pairs that are dissociated and distorted in the dualist dominant paradigm. These include personal aspects such as knowledge and values, cognitive and affective learning, rationality and intuition, object and subject, material and spiritual; and collective aspects such as economy and ecology, present and future, local and global, individual and community.*
9. Systemic and connective	*Putting emphasis on relation and pattern (including dynamics and flows, distortions, feedbacks and causation); encouraging a participative systemic awareness and wisdom in relation to designing sustainable and multilevel physical, environmental, social and economic systems*
10. Ethical	*Clarifying ethical issues, but also nurturing normative ethical sensibility that relates and renders seamless the deeply personal and collective, ie it extends the boundaries of care and concern beyond the immediate and personal to a participative sense of solidarity with others, distant people, environments, species and future generations – what Fox (1992) calls "*transpersonal ethics*". This is neither monist, nor relativist, but reflects an ecological pluralism*
11. Purposive	*Exploring, testing, criticizing and nurturing sustainability values and alternatives, with an explicit intention to assist change*
12. Inclusive and lifelong	*Not selective, but all persons in all areas of life, and extending throughout their life time*

The twelve characteristics helped to define some key concepts to be used in documentary analysis, assuming that when concepts like systemic, contextual, critical, etc. are used in EESD literature they have the meaning presented in the description in *table 1*, and vice versa.

Capra [10] characterizes the change in the learning process "*from transmissive expert-based teaching and learning to transformative community-based learning […], more experimental learning, linking the development of competencies to the "head", "heart" , and "hands"*", with room to collaboration, diversity and systemic thinking.

Educating engineers for sustainable development has been one of the core concerns in engineering education, and it has been a challenge posed not only to higher education but also to the profession itself [11][12]. The *Global Engineer* [13] report defines engineering as "*a global industry undergoing a period of unprecedented change*", and its future is framed by forces such as the impact of globalization, rapid technology advances, climate change and inequality. This document has one of the main perspectives on corporate social responsibility, mapping engineering practice within it. In the UK, the Engineering Council produced new standards of engineering competence, in which engineers have a crucial role to play in minimizing risks, and in bringing about sustainable development throughout the world [14][15]. There are several strategies to integrate sustainable development in engineering education, for example, some programmes had their focus solely on putting engineering activities into a wider context and designing technical solutions to global problems by applying discipline-specific knowledge. Others had their focus on the professional skills required to drive change towards sustainable development, through working in inter-disciplinary teams and considering the wider implications of global societal responsibility [12]. The National Academy of Engineering [15] suggested that the curriculum should be built around developing competences and skills rather just focus in acquire more knowledge, so future engineers can be, for example, creative and flexible.

The *Declaration of Barcelona* [16] frame an engineer identity, who *"understand how their work interacts with society and the environment […], one who has long-term, systemic approach to decision-making, one who is guided by ethics, justice equality and solidarity, and has a holistic understanding that goes beyond his or her own field of specialisation*".

The *Engineering for sustainable development: Guiding principles*, from the Royal Academy of Engineering [17], examined "*the concepts of sustainable development through summaries of projects, products, and actions from across the engineering disciplines*". And from seven case examples pointed twelve guiding principles (divided in sub-principles) of engineering of engineering for sustainable development.

Broadly there is an alignment between the ESD core theories mentioned and the EESD literature, however these reports don't have a clear interpretation of EESD competencies and how can be frame into practice (e.g. learning approaches). One of the main challenges regarding to EESD is to move from broad interpretations of its principles and descriptive examples for more common conceptual framework.

The research question underlying this study was: if there is a common qualification framework (knowledge and competencies) in education for sustainable development (ESD) and in engineering education for sustainable development (EESD)? The aim was to compare core theories of ESD [4][7][8] with more general reports and guidelines for EESD, like *The Global Engineer* [13]; *Declaration of Barcelona* [16], *Engineering for Sustainable Development: Guiding principles* [17].

2 METHODOLOGY

The *Declaration of Barcelona* [16], *The Global Engineer* [13], and *Engineering for Sustainable Development: Guiding Principles* [17] were analysed through content analysis.

The literature review presented three main common points of ESD and EESD: i) sustainable development main themes; ii) learning approach, and iii) learning objectives [3][4][5][7][8][13][14][15][16][17]. The units for analysis were cluster according to these three main common points (named criteria), which also addressed three dimensions of curriculum (*Table 2*).

Table 2. Category and units of analysis

Sustainable development aspects as content [18]	
• Environment • Human Rights • Labour practices and decent work	• Society • Product responsibility • Economic
General learning objectives [4][7][8]	
• Critical thinking • Systems thinking • Collaboration and communication • Lifelong learning	• Creativity and innovative • (Become) Agent of change • Ethics
Learning approach characteristics [4][7][8]	
• Active and independent learners Contextual learning • Experimental learning • Democratic and participatory	• Interdisciplinary to transdisciplinary • Holistic • Integrative

The sustainable development indicators are based on the Global Report Initiatives (GRI) [18], which main goal is to "*communicate clearly and openly about sustainability*", and is defined as "*a globally shared framework of concepts, consistent language, and metrics required*" for reporting sustainability at an organizational level. The GRI provide six main aspects of sustainability (*Table 2*), which are divided in core and additional indicators. Based on these indicators organizations can report about their sustainable development achievements and practices. In the content analysis process the quotes considered indicators, and can be seen in the following section.

3 RESULTS & DISCUSSION

The results are presented in *Table 3*, where in the first column is the criteria and units of analysis applied to the documents for EESD. And in each row are the indicators (which are quotes from the documents analysed) per unit of analysis.

Table 3. Results of the documentary analysis

Sustainable development aspects	***Declaration of Barcelona***	***The Global Engineer***	***Engineering for Sustainable Development***
Environment	"*their work interacts with […] environment*; "*resources efficiency*"; "*pollution prevention*"; "*waste management*" (p. 1)	"*renewable energy*"; "*loss of habitats & biodiversity*"; "*energy*", "*transport*" "*climate change*" (p. 6) …	"*ensure […] that renewable or recycle materials are used*"; "*assess* […] *environment and nature's capacity regeneration*" (p. 27-30
Human Rights	"*different cultural, social and political contexts and take those into account*" "*respect for nature and human rights*" (p. 1)	"*responsibility to act ethically,* […] *involve poor in decision making is becoming recognised by global corporations*" (p. 6)…	"*distinctions between need and want*" (p. 27)

Labour practices and decent work	------	"*Growth in labour mobility, access to knowledge*" (p. 6)….	-----
Society	"*their work interacts with society*"; "*sustainable lifestyle*"(p. 1)	"*impact of poverty on engineering*"; "*conflict, civil unrest and migration*" (p. 6)…	"*participate actively in the decision making as citizens* […] *as professional*" (p. 27)
Product responsibility	-------	"*innovation key to mitigation and adaption* […], *to disaster preparedness and reconstruction*" (p. 6) …	"*low impact products and infrastructures*"(p. 27)
Economic	------	"*low carbon economy specially energy…*"; "*construction markets*"; "*offers economic opportunities*" (p. 6)…	"*engage stakeholders*"; "*sustainable solutions that are competitive will be promoted and propagated by the market*" (p. 27, p. 30)
Elements for learning approach	***Declaration of Barcelona***	***The Global Engineer***	***Engineering for Sustainable Development***
Active and independent learners	"*self-learning*" (p. 2)	"*active learning and practical application*" (p. 12)	------
Contextual (learning)	-----	"*practical application*" (p.12); "*vary according to the local context as well as appropriate tools to investigate and define problems*" (p. 17); "*contextual analysis*" (p. 16)	"*sustainable development redefines the contexts within these skills* (design and manage complex systems) *must be deployed*" (p. 8)
Experimental (learning)	-----	------	------
Democratic and participatory	"*Participate actively in the discussion and definition…*" "*participate and who are able to take responsible decisions*" (p. 2)	------	"*participate actively in decision making*" (p. 27)
Interdisciplinary to transdisciplinary	"*multidisciplinary teams*" (p. 1)	"*provides a interdisciplinary perspective on the problems*" (p. 15)	"*seek engagement from all*" (p. 27) "*the design team appointed* […] *included experts from a wide range of professions*" (p. 35)
Holistic	"*holistic approach* […] *move beyond the tradition of breaking reality down into disconnected parts*" (p. 1)	"*holistic thinking*"; " (p. 12)	"*recognise and exercise their responsibility to society as a whole*" (p. 8); "*adopt a holistic, 'cradle-to-grave' approach*" (p. 29)
Integrative	"*have an integrated approach to knowledge, skills and values*"; "*incorporate disciplines of the social sciences and humanities*" (p. 2)	"*assessing, interrogating and connecting information, generating knowledge* " (p. 12) (p. 17)	"*bring their* (stakeholders) *different views, perceptions, knowledge, and skills to bear on the challenge*" (p. 27)

General learning objectives	*Declaration of Barcelona*	*The Global Engineer*	*Engineering for Sustainable Development*
Critical thinking	"*Stimulate* […] *critical thinking*" (p. 2)	"*reflection*" (p. 12) ; "*critical thinking skills*" (p. 16)	"*assemble and critically review historical evidence*" (p. 28); "*be self-critical*" (p. 30)
Systemic thinking	"*systemic approach to solving problems*" (p. 1)	"*systems thinking and systems engineering*" (p. 16)	"*identify interdependences between economic, social and environmental factors*" (p. 28)
Collaboration and communication	"*multidisciplinary teamwork*" (p. 2)	"*communication skills*" (p. 16); "*team working skills*" (p. 16)	"*we should use teamwork and assistance of immediate colleagues to improve problem definition*" (p. 27)
Lifelong learning	------	"*continuous learner*" (p. 12)	"*sustainable development depends on investigating for jam tomorrow and for bread and butter today*" (p. 29)
Creativity and innovative	*"Stimulate creativity"* (p. 2)	"*creative and conception skills*" (p. 16)	"*A sustainable development approach is creative, innovative and broad*" (p. 26)
(Become) Agent of change	"*help redirect society towards more sustainable development*" (p. 2)	"*living with difference and conflict and shifting positions and perspectives according to contexts*" (p. 12); "*adapt and modify approaches*" (p. 17)	"*Improved sustainability will result from the actions proposed*" (p. 28)
Ethics	"*professional knowledge according to deontological principles and universal values and ethics*" (p. 2)	"*Integrity and trustworthiness*"; "*appropriate values*" (p. 12)	"*self-critical of our fundamental assumptions and values*"; "*avoid sacrificing the sustainability desires…*" (p. 30)

The quotes are not exhaustive but rather exemplary of what the three documents considered as part the discourse for engineering education for sustainable development (EESD). Not all the documents analysed presented clear example of the elements presented.

3.1 Discussion

The sustainable development aspects considered for analysis were found in the three documents analysed. More in *The Global engineer* report and *Engineering Education for Sustainable Development* rather than in the *Declaration of Barcelona (Table 3)*.

The *Declaration of Barcelona* is a two pages document and has it main focus in the learning process for engineering education for sustainable development (EESD) rather than sustainable development themes where engineers should work on. Its main sustainable development themes are environment, society even if stated very broadly. In comparison, *The Global Engineer* presented examples regarding to all aspects of sustainable development considered for analysis. This document also maps the impact and linkages between climate change, poverty, globalisation and engineering practice [13]. The *Engineering for Sustainable Development: Guiding Principles* pointed twelve principles from the analysis of good examples of engineering for sustainable development, pointing perspectives, procedures,

actors involved, attitudes, etc. and which were placed in accordance with units of analysis from *Table 3*.
The three documents analysed also present the same learning objectives and characteristics for a learning environment that the core theories for ESD. With the exception of the experimental learning which was more implicit rather than explicit and for this reason was not included in *Table 3*. On the other hand, there are key elements that are stressed in the three documents: interdisciplinarity; holistic and integrative for learning approach; critical and systems thinking; collaboration and communication; creativity and innovation; agent of change and ethics for learning objectives. There was an aspect that was not considered in the table 3 but which was considered central in the documents analysed. It was the presence of the word "*problem*". It seems that it is central for EESD the ability to define, analyse and solve and problems, as well as reflect on decisions and their consequences.

4 CONCLUSIONS

The results presented help to build a common understanding of the complexity of sustainable development in engineering, and what are their implications for engineering education.
In general, the documents analysed enclosure aspects of the three dimensions of sustainable development and argue for them with examples of engineering practices, stressing the central role of engineering and the alignment of the discipline specific knowledge with others disciplines aiming a responsible and conscience action. Also the competences needed to achieve sustainable actions are common to the three documents, and are aligned with ESD core theories as well as the characteristics of the learning approach. This study provided an instrument for meta-analysis in three interconnected axis for EESD: i) sustainable development themes/ aspects to address; ii) general learning objectives (competences and skills); iii) characteristics of the learning approach. This framework encloses a conceptual dimension and methodological framework. The conceptual dimension is related with the common understanding between different types of literature in relation with EESD qualification framework. Methodologically, the framework can be used as an instrument for analysis and change.

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